Instrument Kernel
IK

October 2022

Purpose

- **The Instrument Kernel serves as a repository for instrument-specific geometry information useful within the SPICE context.**
  - **Always included:**
    - » **If an instrument has a field-of-view (FOV), specifications for an instrument's size, shape, and orientation**
  - **Other possibilities:**
    - » **Timing parameters**
    - » **Optical parameters**
    - » **Detector geometric parameters**
    - » **Optical distortion parameters**

- **An antenna or solar array or other structure for which pointing is important can also use the IK**

- **Note: instrument mounting alignment data are specified in a mission's Frames Kernel (FK)**

- **An I-Kernel is a SPICE text kernel. The format and structure of a typical I-Kernel is shown below.**

```
KPL/IK
    Comments describing the keywords and values
    to follow, as well as any other pertinent
    information.

        \begindata
            Keyword = Value(s) Assignment
            Keyword = Value(s) Assignment

        \begintext

More descriptive comments.

        \begindata
            Keyword = Value(s) Assignment
        \begintext

More descriptive comments.
                etc ...
```

I-Kernel Contents (1)

- **The requirements on keywords in an IK are the following:**
  - **Keywords must begin with INS[#], where [#] is replaced with the NAIF instrument ID code (which is a negative number)**
  - **The total length of the keyword must be less than or equal to 32 characters**
  - **Keywords are case-sensitive (Keyword != KEYWORD)**

- **Examples of IK keywords, with descriptions:**
  - **INS-94031_FOCAL_LENGTH   MGS MOC NA focal length**
  - **INS-41220_IFOV   MEX HRSC SRC pixel angular size**
  - **INS-41130_NUMBER_OF_SECTORS   MEX ASPERA NPI number of sectors**

- **In general SPICE does not require any specific keywords to be present in an IK**
  - **One exception is a set of keywords defining an instrument's FOV, if the SPICE Toolkit's GETFVN or GETFOV routine is planned to be used to retrieve the FOV attributes**

- **IKs should contain extensive comments regarding:**
  - **Instrument overview**
  - **Reference source(s) for the data included in the IK**
  - **Names/IDs assigned to the instrument and its parts**
  - **Explanation of each keyword included in the file**
  - **Description of the FOV and detector layout**
  - **Where appropriate, descriptions of the algorithms in which parameters provided in the IK are used, and even fragments of source code implementing these algorithms**
    - » **For example optical distortion models or timing algorithms**

- **These comments exist primarily to assist users in integrating I-Kernel data into their applications**
  - **One needs to know the keyword name to get its value(s) from the IK data**
  - **One needs to know what each value means in order to use it properly**
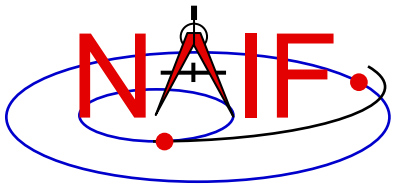
I-Kernel Interface Routines

- **As with any SPICE kernel, an IK is loaded using FURNSH**

  ```
  CALL FURNSH ( 'ik_file_name.ti' )          {Better yet, use a FURNSH kernel}
  ```

- **By knowing the name and type (DP, integer, or character) of a keyword of interest, the value(s) associated with that keyword can be retrieved using G*POOL routines**

  ```
  CALL GDPOOL ( NAME, START, ROOM, N, VALUES, FOUND ) for DP values
  CALL GIPOOL ( NAME, START, ROOM, N, VALUES, FOUND ) for integer values
  CALL GCPOOL ( NAME, START, ROOM, N, VALUES, FOUND ) for character strings
  ```

- **When an instrument's FOV is defined in the IK using a special set of keywords discussed later in this tutorial, the FOV shape, reference frame, boresight vector, and boundary vectors can be retrieved by calling the GETFVN and GETFOV routines**

  ```
  CALL GETFVN ( INSNAM, ROOM, SHAPE, FRAME, BSIGHT, N, BOUNDS)

  CALL GETFOV ( INSTID, ROOM, SHAPE, FRAME, BSIGHT, N, BOUNDS)
  ```

FORTRAN examples are shown
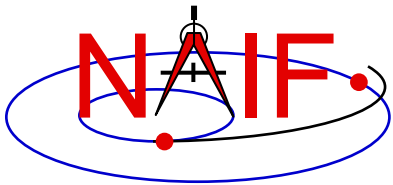
Navigation and Ancillary Information Facility

- **The following keywords defining FOV attributes for the instrument with NAIF ID (#) must be present in the IK if the SPICE Toolkit's GETFNV or GETFOV module will be used**

    - **Keyword defining shape of the FOV**

    ```
    INS#_FOV_SHAPE      = 'CIRCLE' or 'ELLIPSE' or
                          'RECTANGLE' or 'POLYGON'
    ```
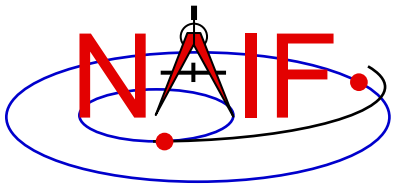
    - **Keyword specifying the reference frame in which the boresight vector and FOV boundary vectors are specified**

    ```
    INS#_FOV_FRAME      = 'frame name'
    ```

    - **Keyword defining the boresight vector**

    ```
    INS#_BORESIGHT      = ( X, Y, Z )
    ```

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– **Keyword(s) defining FOV boundary vectors, provided in either of two ways**

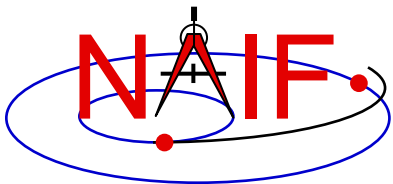**1) By specifying boundary vectors explicitly**

```
INS#_FOV_CLASS_SPEC        = 'CORNERS'
INS#_FOV_BOUNDARY_CORNERS = ( X(1), Y(1), Z(1),
                              ...    ...    ...
                              X(n), Y(n), Z(n) )
```

where the `FOV_BOUNDARY_CORNERS` keyword provides an array of vectors that point to the "corners" of the instrument field of view.

Note: Use of the `INS#_FOV_CLASS_SPEC` keyword is optional when explicit boundary vectors are provided.

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Navigation and Ancillary Information Facility

2) By providing half angular extents of the FOV (possible only for circular, elliptical or rectangular FOVs)

```
INS#_FOV_CLASS_SPEC          = 'ANGLES'
INS#_FOV_REF_VECTOR          = ( X, Y, Z )
INS#_FOV_REF_ANGLE           = halfangle1
INS#_FOV_CROSS_ANGLE         = halfangle2
INS#_FOV_ANGLE_UNITS         = 'DEGREES' or
                               'RADIANS' or …
```

where the `FOV_REF_VECTOR` keyword specifies a reference vector that, together with the boresight vector, define the plane in which the half angle given in the `FOV_REF_ANGLE` keyword is measured. The other half angle given in the `FOV_CROSS_ANGLE` keyword is measured in the plane normal to this plane and containing the boresight vector.
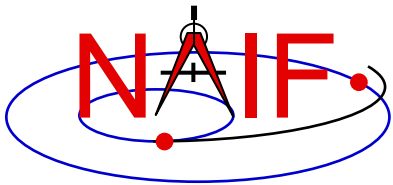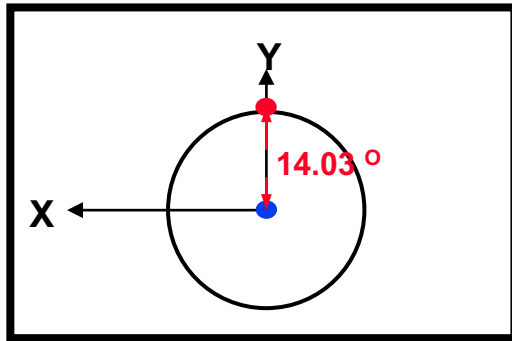
Navigation and Ancillary Information Facility

- **When explicit boundary vectors are provided, they must be listed in either clockwise or counter-clockwise order, not randomly**
- **Neither the boresight nor reference vector has to be co-aligned with one of the FOV frame's axes**
  - **But for convenience, each is frequently defined to be along one of the FOV axes**
- **None of the boresight, corner or reference vector has to be a unit vector**
  - **But these frequently are defined as unit vectors**
- **When a FOV is specified using the half angular extents method, the boresight and reference vectors have to be linearly independent but they don't have to be perpendicular**
  - **But for convenience the reference vector is usually picked to be normal to the boresight vector**
- **Half angular extents for a rectangular FOV specify the angles between the boresight and the FOV sides, i.e. they are for the middle of the FOV**
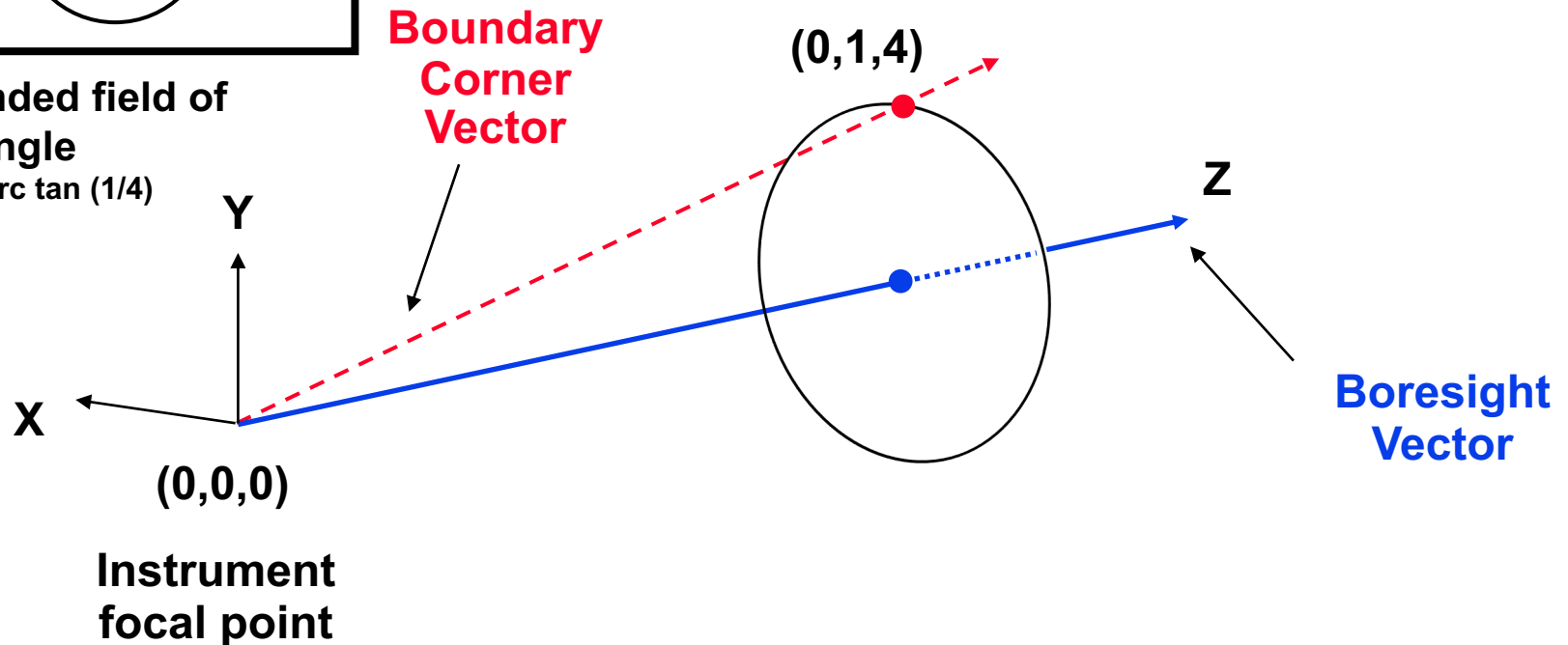- **The next several pages show examples of FOV definitions**
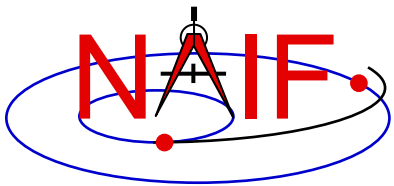
Instrument Kernel

Consider an instrument with a circular field of view.
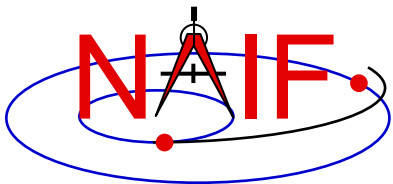
Y

14.03 °

X

Subtended field of view angle
14.03 = arc tan (1/4)

Boundary Corner Vector

(0,1,4)

Y

Z

X

Boresight Vector

(0,0,0)

Instrument focal point

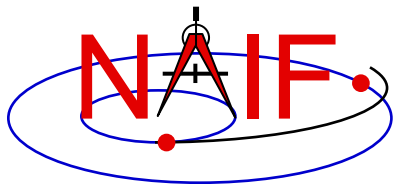**Navigation and Ancillary Information Facility**

The following sets of keywords and values describe this circular field of view:

Specifying boundary vectors explicitly:

```
INS-11111_FOV_SHAPE            = 'CIRCLE'
INS-11111_FOV_FRAME            = 'FRAME_FOR_INS-11111'
INS-11111_BORESIGHT            = ( 0.0  0.0  1.0 )
INS-11111_FOV_BOUNDARY_CORNERS = ( 0.0  1.0  4.0 )
```

Specifying half angular extents of the FOV:
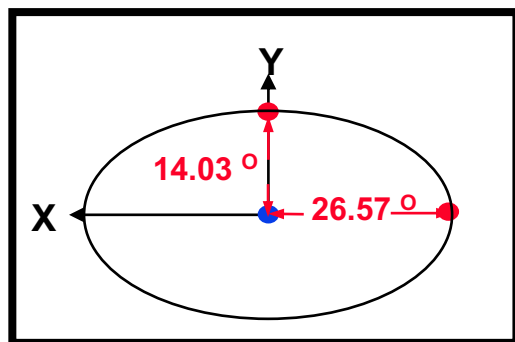
```
INS-11111_FOV_SHAPE            = 'CIRCLE'
INS-11111_FOV_FRAME            = 'FRAME_FOR_INS-11111'
INS-11111_BORESIGHT            = ( 0.0  0.0  1.0 )
INS-11111_FOV_CLASS_SPEC       = 'ANGLES'
INS-11111_FOV_REF_VECTOR       = ( 0.0  1.0  0.0 )
INS-11111_FOV_REF_ANGLE        = 14.03624347
INS-11111_FOV_ANGLE_UNITS      = 'DEGREES'
```

Consider an instrument with an elliptical field of view.
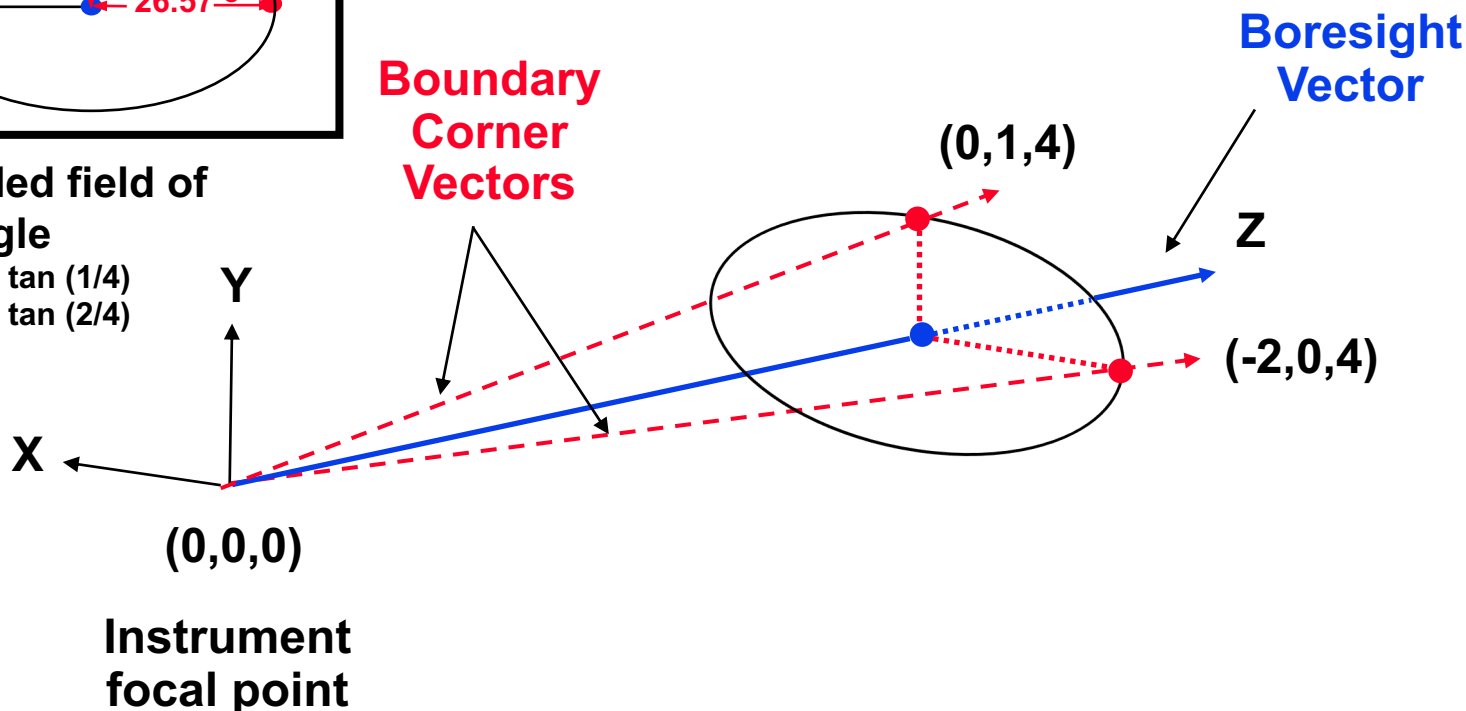
14.03 °

26.57 °

X

Y

Subtended field of view angle
14.03 = arc tan (1/4)
26.57 = arc tan (2/4)

Boundary Corner Vectors

Boresight Vector

(0,1,4)

(-2,0,4)

Z

Y

X
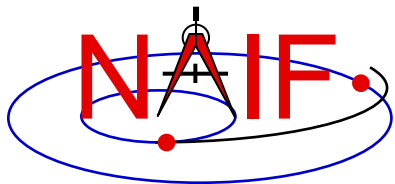
(0,0,0)

Instrument focal point

The following sets of keywords and values describe this elliptical field of view:

Specifying boundary vectors explicitly:

```
INS-22222_FOV_SHAPE           = 'ELLIPSE'
INS-22222_FOV_FRAME           = 'FRAME_FOR_INS-22222'
INS-22222_BORESIGHT           = ( 0.0  0.0  1.0 )
INS-22222_FOV_BOUNDARY_CORNERS = ( 0.0  1.0  4.0
                                  -2.0  0.0  4.0 )
```
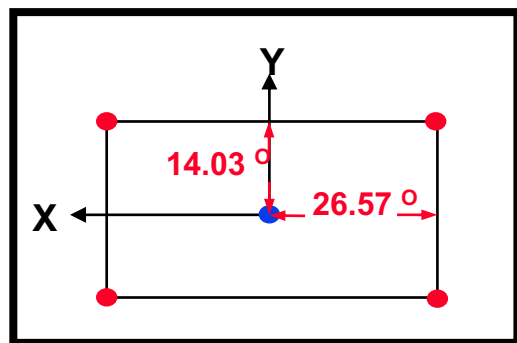
Specifying half angular extents of the FOV:

```
INS-22222_FOV_SHAPE           = 'ELLIPSE'
INS-22222_FOV_FRAME           = 'FRAME_FOR_INS-22222'
INS-22222_BORESIGHT           = ( 0.0  0.0  1.0 )
INS-22222_FOV_CLASS_SPEC      = 'ANGLES'
INS-22222_FOV_REF_VECTOR      = ( 0.0  1.0  0.0 )
INS-22222_FOV_REF_ANGLE       = 14.03624347
INS-22222_FOV_CROSS_ANGLE     = 26.56505118
INS-22222_FOV_ANGLE_UNITS     = 'DEGREES'
```
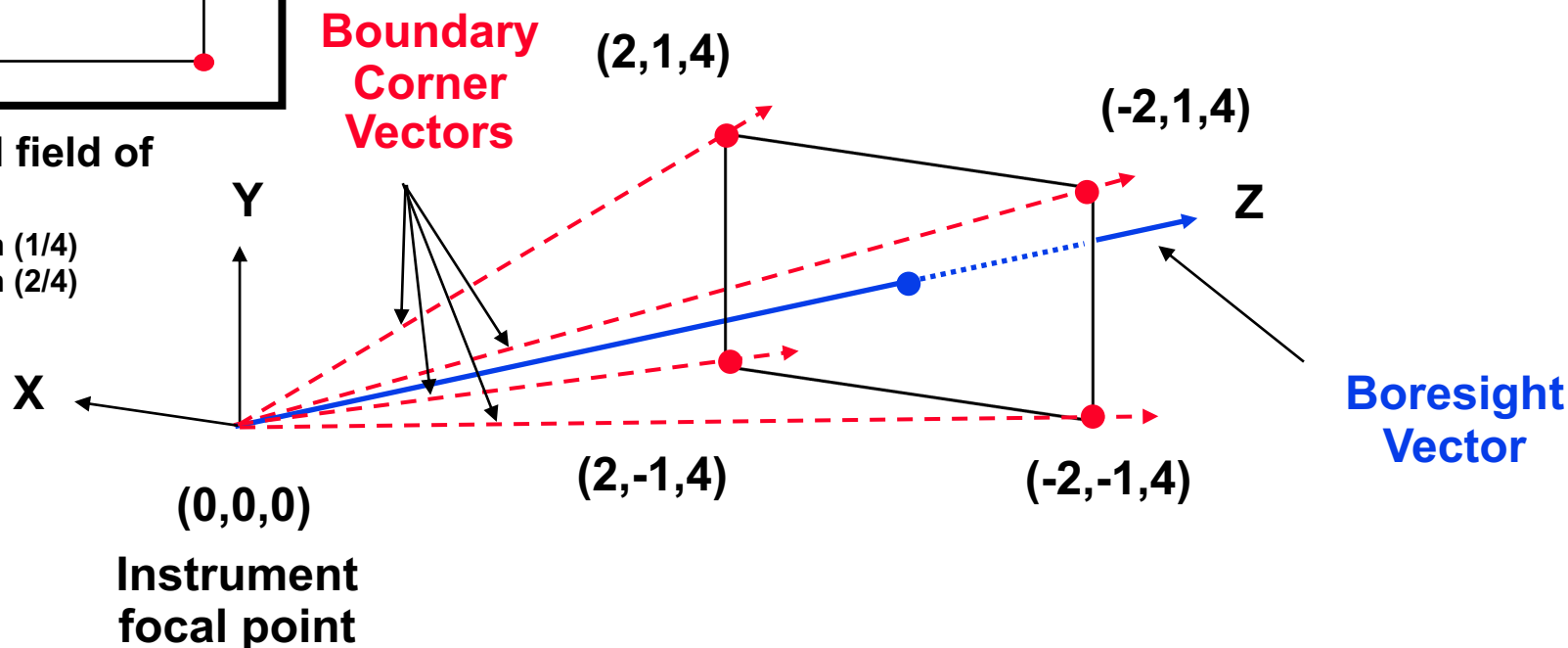
Navigation and Ancillary Information Facility

Consider an instrument with a rectangular field of view.

Y

14.03 °

26.57 °

X

Subtended field of view angle
14.03 = arc tan (1/4)
26.57 = arc tan (2/4)

Boundary Corner Vectors

(2,1,4)

(-2,1,4)

Y

Z

X

Boresight Vector

(2,-1,4)

(-2,-1,4)

(0,0,0)

Instrument focal point

Instrument Kernel

Rectangular FOV Definition

The following sets of keywords and values describe this rectangular field of view:

Specifying boundary vectors explicitly:

```
INS-33333_FOV_SHAPE            = 'RECTANGLE'
INS-33333_FOV_FRAME            = 'FRAME_FOR_INS-33333'
INS-33333_BORESIGHT            = ( 0.0  0.0  1.0 )
INS-33333_FOV_BOUNDARY_CORNERS = ( 2.0  1.0  4.0
                                  -2.0  1.0  4.0
                                  -2.0 -1.0  4.0
                                   2.0 -1.0  4.0 )
```

Specifying half angular extents of the FOV:

```
INS-33333_FOV_SHAPE            = 'RECTANGLE'
INS-33333_FOV_FRAME            = 'FRAME_FOR_INS-33333'
INS-33333_BORESIGHT            = ( 0.0  0.0  1.0 )
INS-33333_FOV_CLASS_SPEC       = 'ANGLES'
INS-33333_FOV_REF_VECTOR       = ( 0.0  1.0  0.0 )
INS-33333_FOV_REF_ANGLE        = 14.03624347
INS-33333_FOV_CROSS_ANGLE      = 26.56505118
INS-33333_FOV_ANGLE_UNITS      = 'DEGREES'
```

Navigation and Ancillary Information Facility

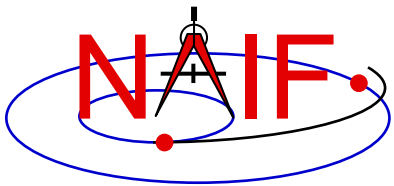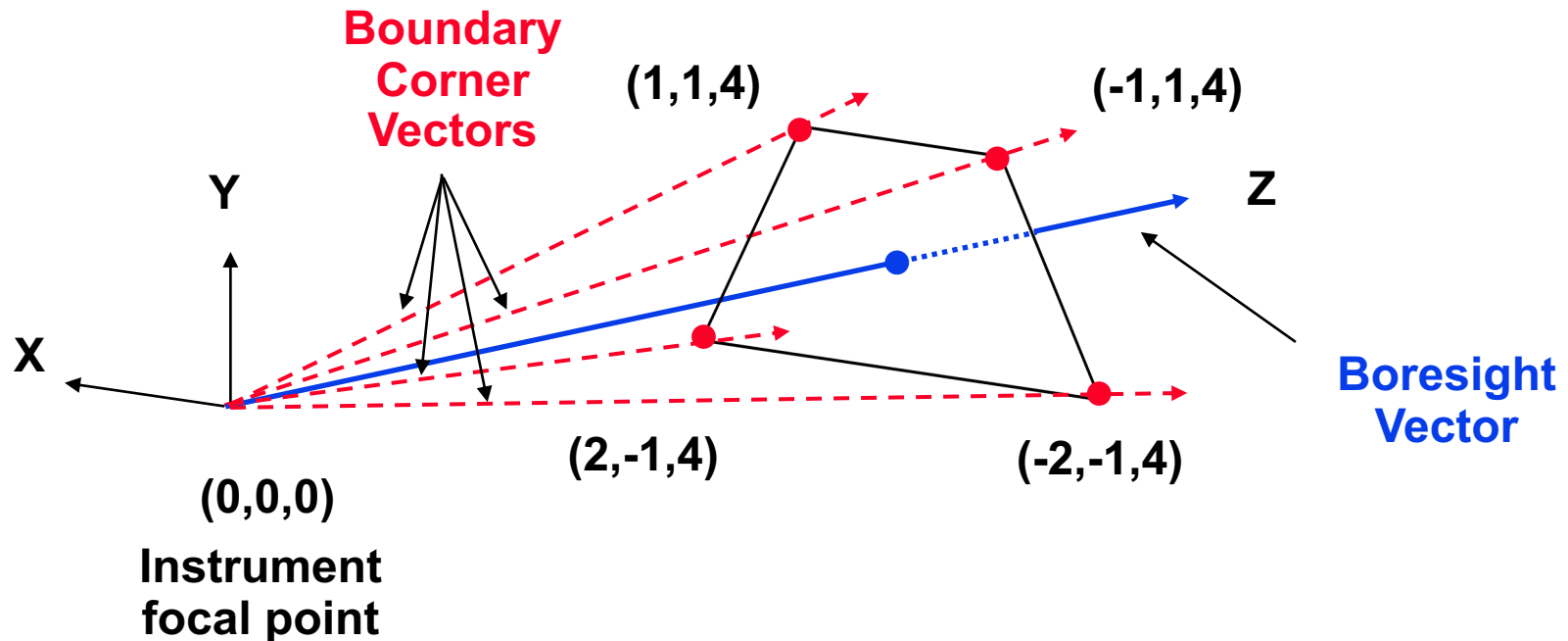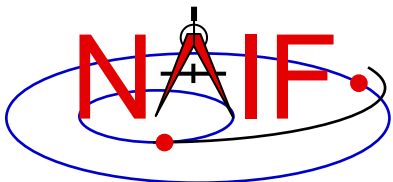## Consider an instrument with a trapezoidal field of view.

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The following sets of keywords and values describe this polygonal field of view:

Specifying boundary vectors explicitly:

```
INS-44444_FOV_SHAPE            = 'POLYGON'
INS-44444_FOV_FRAME            = 'FRAME_FOR_INS-44444'
INS-44444_BORESIGHT            = ( 0.0  0.0  1.0 )
INS-44444_FOV_BOUNDARY_CORNERS = ( 1.0  1.0  4.0
                                  -1.0  1.0  4.0
                                  -2.0 -1.0  4.0
                                   2.0 -1.0  4.0 )
```

• A polygonal FOV cannot be specified using half angular extents.
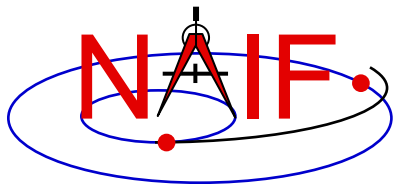
IK Utility Programs

- **No IK utility programs are included in the Toolkit**

- **Two IK utility programs are provided on the NAIF website (https://naif.jpl.nasa.gov/naif/utilities.html)**

    OPTIKS   displays field-of-view summary for all FOVs defined in a collection of IK files.

    BINGO   converts IK files between UNIX and DOS text formats

Additional Information on IK

- **The best way to learn more about IKs is to examine some found in the NAIF Node archives.**
  - **Start looking here:**

    https://naif.jpl.nasa.gov/naif/data_archived.html

- **NAIF does not yet have an "I-Kernel Required Reading" document**

- **But information about IKs is available in other documents:**
  - **header of the GETFOV routine**
  - **Kernel Required Reading**
  - **OPTIKS User's Guide**
  - **Porting_kernels tutorial**
  - **NAIF IDs Tutorial**
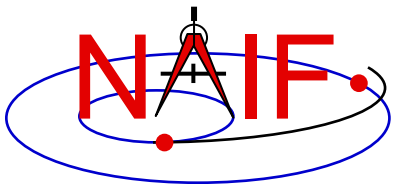 - **Frames Required Reading**

Navigation and Ancillary Information Facility

- **The best way to learn more about IKs is to examine some found in the NAIF Node archives.**
  - **Start looking here:**

   **https://naif.jpl.nasa.gov/naif/data_archived.html**

- **NAIF does not yet have an "I-Kernel Required Reading" document**

- **But information about IKs is available in other documents:**
  - **headers of the GETFVN and GETFOV routines**
  - **Kernel Required Reading**
  - **OPTIKS User's Guide**
  - **Porting_kernels tutorial**
  - **NAIF IDs Tutorial**
  - **Frames Required Reading**

Instrument Kernel

Backup

- **IK file example**

- **Computing angular extents from corner vectors returned by GETFOV**
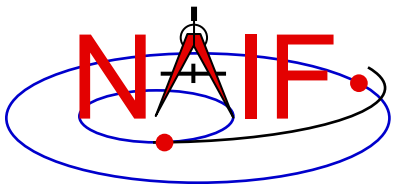
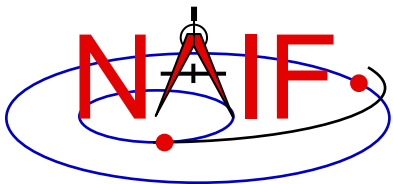## The following LEMMS1 FOV definition was taken from the Cassini MIMI IK (cas_mimi_v11.ti):

```
Low Energy Magnetospheric Measurements System 1 (LEMMS1)

   Since the MIMI_LEMMS1 detector's FOV is circular and it's diameter is 15.0
   degrees, looking down the X-axis in the CASSINI_MIMI_LEMMS1 frame, we have:
   (Note we are arbitrarily choosing a vector that terminates in the Z=1
   plane.)


                              ^ Y
                              |  ins
                              |
                              |        /|
                              |       /  |
                              |      /   |
                              |   /    o |
                              |/  7.50  |
                              x--------------->
                             X  \        |      Z
                              ins \       |       ins
                                    \     |
                                      \   |
                                        \|

                             |-- 1.0 --|
```
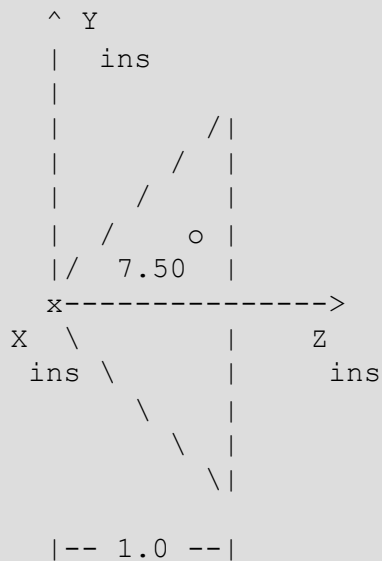
continues

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FOV definition from the Cassini MIMI IK (continued):

```
The Y component of one 'boundary corner' vector is:

        Y Component = 1.0 * tan ( 7.50 degrees )
                    = 0.131652498

   The boundary corner vector as displayed below is
   normalized to unit length:
\begindata

 INS-82762_FOV_FRAME  = 'CASSINI_MIMI_LEMMS1'
 INS-82762_FOV_SHAPE  = 'CIRCLE'
 INS-82762_BORESIGHT  = (

  0.0000000000000000   0.0000000000000000  +1.0000000000000000


                          )
 INS-82762_FOV_BOUNDARY_CORNERS = (

  0.0000000000000000  +0.1305261922200500  +0.9914448613738100


                             )

\begintext
```
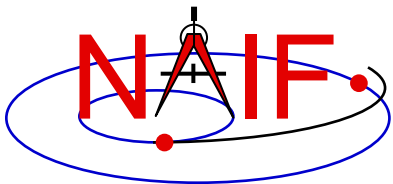
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The angular separation between the boundary corner vector and the boresight is the angular size.

FORTRAN EXAMPLE

```
C    Retrieve FOV parameters.
     CALL GETFOV(-11111, 1, SHAPE, FRAME, BSGHT, N, BNDS)

C    Compute the angular size.
     ANGSIZ = VSEP( BSGHT, BNDS(1,1) )
```
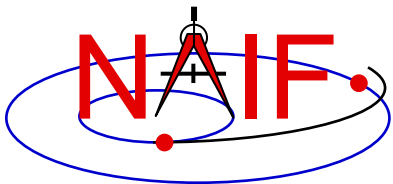
C EXAMPLE

```
/*  Define the string length parameter. */
    #define STRSIZ        80

/*  Retrieve the field of view parameters. */
    getfov_c(-11111, 1, STRSIZ, STRSIZ, shape, frame,
            bsght, &n, bnds);

/*  Compute the angular separation. */
    angsiz = vsep_c( bsght, &(bnds[0][0]));
```
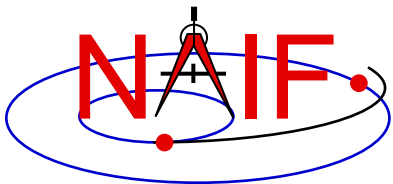
Elliptical FOV Angular Size - 1

The angular sizes are the angular separations between the boresight and the boundary vectors.

<p align="center">**FORTRAN EXAMPLE**</p>

```
C    Retrieve the FOV parameters from the kernel pool.
     CALL GETFOV(-22222, 2, SHAPE, FRAME, BSGHT, N, BNDS)

C    Compute the angular separations.
     ANG1   = VSEP( BSGHT, BNDS(1,1) )
     ANG2   = VSEP( BSGHT, BNDS(1,2) )

C    The angle along the semi-major axis is the larger
C    of the two separations computed.
     LRGANG = MAX( ANG1, ANG2)
     SMLANG = MIN( ANG1, ANG2)
```

Navigation and Ancillary Information Facility

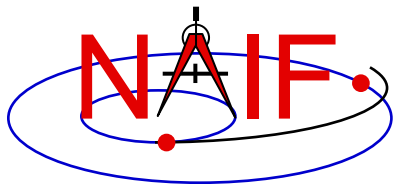<u>**C EXAMPLE**</u>

```
/*   Define the string length parameter. */
     #define STRSIZ        80


/*   Retrieve the FOV parameters from the kernel pool. */
     getfov_c(-22222, 2, STRSIZ, STRSIZ, shape, frame,
              bsght, &n, bnds);


/*   Compute the angular separations. */
     ang1 = vsep_c( bsght, &(bnds[0][0]));
     ang2 = vsep_c( bsght, &(bnds[1][0]));


/*   The angle along the semi-major axis is the larger of the
     two separations computed. */
     if ( ang1 > ang2 ) {
        lrgang = ang1; smlang = ang2; }
     else {
        lrgang = ang2; smlang = ang1; }
```
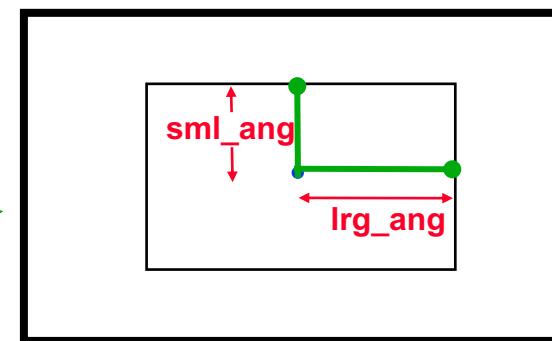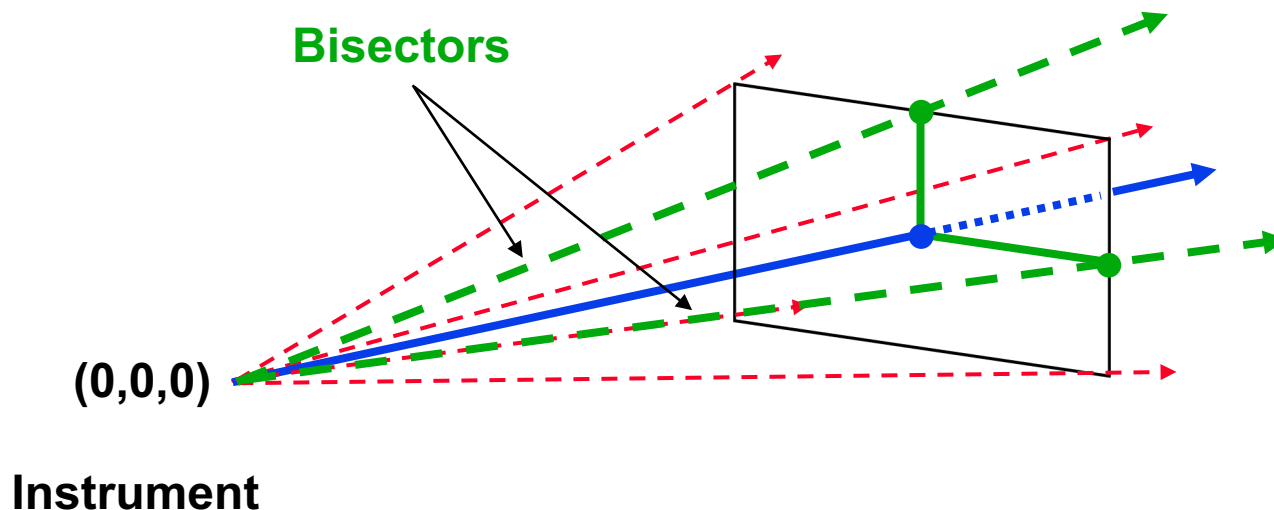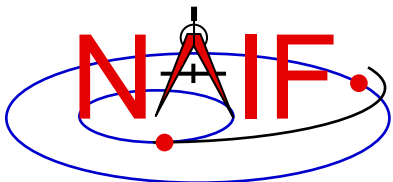
The angular extents of the FOV are computed by calculating the angle between the bisector of adjacent unit boundary vectors and the boresight.

Bisectors

(0,0,0)

Instrument

sml_ang

lrg_ang

Subtended field of view angles

FORTRAN EXAMPLE

```
C     Retrieve FOV parameters from the kernel pool.
      CALL GETFOV(-33333, 4, SHAPE, FRAME, BSGHT, N, BNDS)

C     Normalize the 3 boundary vectors
      CALL UNORM(BNDS(1,1), UNTBND(1,1), MAG)
      CALL UNORM(BNDS(1,2), UNTBND(1,2), MAG)
      CALL UNORM(BNDS(1,3), UNTBND(1,3), MAG)

C     Compute the averages.
      CALL VADD(UNTBND(1,1), UNTBND(1,2), VEC1)
      CALL VSCL(0.5, VEC1, VEC1)

      CALL VADD(UNTBND(1,2), UNTBND(1,3), VEC2)
      CALL VSCL(0.5, VEC2, VEC2)

C     Compute the angular separations
      ANG1  = VSEP( BSGHT, VEC1 )
      ANG2  = VSEP( BSGHT, VEC2 )

C     Separate the larger and smaller angles.
      LRGANG = MAX( ANG1, ANG2)
      SMLANG = MIN( ANG1, ANG2)
```
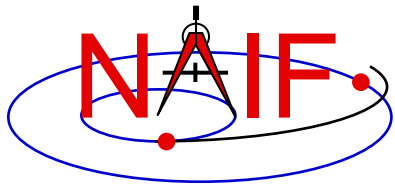
Navigation and Ancillary Information Facility

<u>**C EXAMPLE**</u>

```c
/*   Define the string length parameter. */
     #define STRSIZ          80


/*   Retrieve the FOV parameters from the kernel pool. */
     getfov_c(-33333, 4, STRSIZ, STRSIZ, shape, frame,
              bsght, &n, bnds);


/*   Normalize the 3 boundary vectors. */
     unorm_c(&(bnds[0][0]), &(untbnd[0][0]), &mag);
     unorm_c(&(bnds[1][0]), &(untbnd[1][0]), &mag);
     unorm_c(&(bnds[2][0]), &(untbnd[2][0]), &mag);


/*   Compute the averages */
     vadd_c(&(untbnd[0][0]), &(untbnd[1][0]), vec1);
     vscl_c(0.5, vec1, vec1);
     vadd_c(&(untbnd[1][0]), &(untbnd[2][0]), vec2);
     vscl_c(0.5, vec2, vec2);


/*   Compute the angular separations. */
     ang1 = vsep_c( bsght, vec1);
     ang2 = vsep_c( bsght, vec2);


/*   Separate the larger and smaller angles. */
     if ( ang1 > ang2 ) {
        lrgang = ang1; smlang = ang2; }
     else {
        lrgang = ang2; smlang = ang1; }
```

Instrument Kernel